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JOURNEY TO THE SHELF

HOW VIRTUAL TESTING CUTS TIME AND COSTS IN HALF TO MAKE, FILL, AND SHIP NEW PACKAGING

Bottle designers often create beautiful, innovative concepts, but retreat to conventional square, cylindrical, or rectangular shapes if the bottle can't move efficiently through the filling and shipping process.

Virtual Testing enables designers to simulate how a new bottle design will behave at every stage of its lifecycle, lowering costs, improving sustainability and driving consumers to put their products in shopping baskets.

BLOW MOLDING

Reduces raw material costs by optimizing preform shape to produce the desired final thickness distribution.

CONVEYING

Reduces damage cost by ensuring bottles won't get stuck or tip over in the assembly line.

FILLING

Predicts how the package will behave after filling the product and measures the filled volume.

LABELING

Improves package quality by predicting if new bottle design will cause tearing or wrinkling of labels.

CAPPING

Estimates amount of torque required to open and close the cap while maintaining seal integrity.

CASING

Reduces shipping damage by predicting final package shape in shrink wrap and whether the case can sustain shape during handling.

PALLETING

Reduces bottle breakage by predicting bottle behavior from top-load (of bottle weight) in a pallet.

THE BENEFITS OF VIRTUAL TESTING

18 > 9 MONTHS
Reduction in design cycle when you reduce the need for physical prototypes through virtual testing.[1]

1 WEEK > 1 HOUR
Amount of time by which process automation can reduce design iteration.[2]

75%
Reduction of package development time and effort.[3]

27%
Reduction of raw materials experienced by some manufacturers using virtual testing.[1]

3-6 MONTHS
Amount of time saved due to simulation during palleting design phase.[4]

50%
Amount of time saved in redesign cycle by running a capping simulation.[5]

MILLIONS
Dollars saved by shaving off just a few grams from packaging when billions of units are produced.[1]

Go to **www.3ds.com/process-mfg** to learn more.

1. *Amcor designs reduced-plastic bottles with Dassault Systèmes PLM*
Amcor, Customer Story, 2011

2. *Keeping Carbonation Bottled Up with FEA*
Saint-Gobain, SIMULIA Community News, 2013

3. *Aluminum Bottle Forming Simulation with Abaqus*
The Coca-Cola Company and Dassault Systèmes, SIMULIA Community Conference Paper, 2009

4. *Silgan Containers Uses State-of-the Art Simulation Software for Predicting Can Performance*
Silgan Containers, Realistic Simulation News, May 2009

5. *Closure System Bottle Cap Redesign*
Closure Systems International

Application of Abaqus and Isight Simulation on Corrugated Board and Packaging

Arnoud Dekker (Smurfit Kappa Development Centre)

Abstract: The presentation is about the application and impact of Abaqus and iSight simulations for corrugated board and packaging within Smurfit Kappa. Abaqus and Isightare used for the development of the prediction formulas, used in our prediction tool PaperToBox. PaperToBox is considered as industry leading. This tool is internally used by 1800 colleagues, resulting in >500 000 calculations per year. Also this tool provides the target values for the newly rolled-out quality measurement system, the "Board Referee".

Smurfit Kappa is one of the leading providers of paper-based packaging solutions in the world, with around 42,000 employees in approximately 350 production sites across 32 countries and with revenue of €8.1 billion in 2014. We are located in 21 countries in Europe, and 11 in the Americas. We are the only large-scale pan-regional player in Latin America. With our pro-active team we relentlessly use our extensive experience and expertise, supported by our scale, to open up opportunities for our customers. We collaborate with forward thinking customers by sharing superior product knowledge, market understanding and insights in packaging trends to ensure business success in their markets. We have an unrivalled portfolio of paper-packaging solutions, which is constantly updated with our market-leading innovations. This is enhanced through the benefits of our integration, with optimal paper design, logistics, timeliness of service, and our packaging plants sourcing most of their raw materials from our own paper mills. Our products, which are 100% renewable and produced sustainably, improve the environmental footprint of our customers. Our headquarters are in Dublin with regional headquarters in Paris (Europe) and Miami (the Americas).

Keywords: Corrugated Board, Bending strength, Design Of Experiments, Response Surface Creation

1. INTRODUCTION

The presentation is about the application and impact of Abaqus and iSight simulations for corrugated board and packaging within Smurfit Kappa.

The shown example is the use of Abaqus and Isight for the development of the prediction formulas, used in our prediction tool PaperToBox. PaperToBox is considered as industry leading. This tool is internally used by 1800 colleagues, resulting in >500 000 calculations per year. Also this tool provides the target values for the newly rolled-out quality measurement system, the "Board Referee".

2. FORMULA DEVELOPMENT FOR PAPER TO BOX

The first example is the use of Abaqus and Isight for the development of the prediction formulas, used in our prediction tool PaperToBox. PaperToBox is considered as industry leading. This tool is internally used by >1800 colleagues, resulting in >500 000 calculations per year. Also this tool provides the target values for the newly rolled-out quality measurement system, the "Board Referee", which measures the bending strength of corrugated board.

2.1 Work flow

The complete work flow is starting with the FEA model and ends with business application, see picture 1.

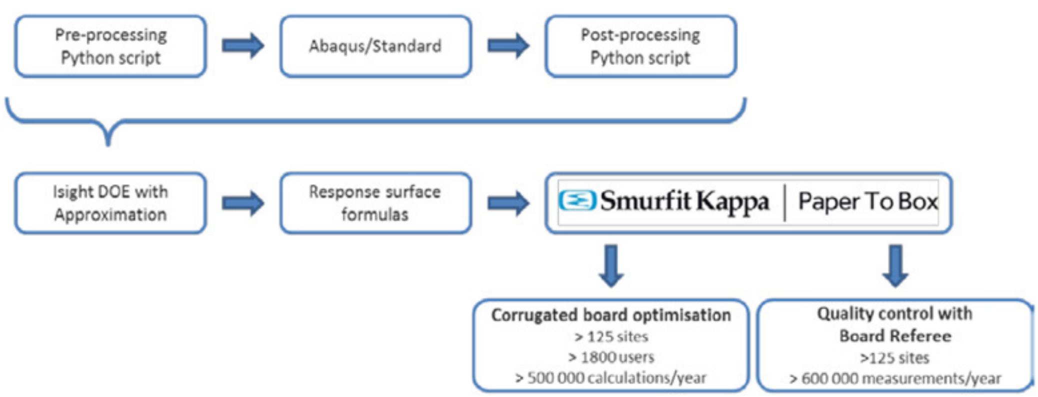


Figure 1. Work flow from FEA to the business.

Source: 2015 SIMULIA Community Conference

2.2 Pre-processing and post-processing with Python

The use of Isight requires fully parametric FEA models. Using Python scripts for pre-processing and post-processing is needed, because the whole geometry of the corrugated board is dependent on complex formulas. Abaqus/CAE is used as the pre- and post-processor.

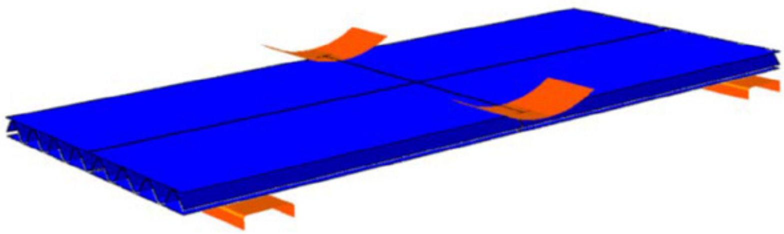


Figure 2. Bending strength model.

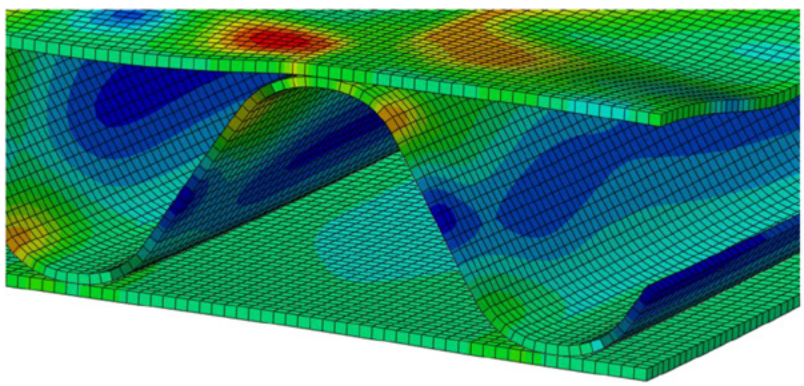


Figure 3. Detail of bending strength model.

2.3 Using Isight for generating response surface formulas

With Isight a DOE is created based on the properties and value range of the PaperToBox input. For the different flute types, a full factorial DOE with selected parameters was run..

In Isight the DOE component in combination with simcode component is used. In the simcode component each FEA model is generated with a pre-processing Python script using Abaqus/CAE, run with Abaqus/Standard and post-processed with a post-processing Python script, again using Abaqus/CAE.

After the DOE has run, the approximation function with quartic polynomals is used to generate the response surface. The error using the approximation function was less than 1% for any sample point. These formulas can be directly copied into Excel with minor editing.

2.4 Implementation in PaperToBox and subsequent usage

The Excel file with the response surface formulas is embedded in PaperToBox, an in-house developed web-based application. This allows all the users (>1800) in the corrugated board and packaging plants (>125) to use PaperToBox and have instantaneous results for their calculations.

This allows the Smurfit Kappa plants to optimize the paper usage (> 3000 M€) in the corrugated board and packaging.

Also PaperToBox provides the target values for the newly rolled-out quality measurement system, the "Board Referee", which measures the bending strength of corrugated board. the corrugated board and packaging plants (>125) will measure more than 600 000 samples per year.

Source: 2015 SIMULIA Community Conference

Figure 4. Board Referee, developed by Smurfit Kappa.

3. REFERENCES

Abaqus Users Manual, Version 6.13-1, Dassault Systémes Simulia Corp., Providence, RI.

Source: 2015 SIMULIA Community Conference

Plastic Technologies, Inc. Takes a Deep Dive into Container Simulation to Gain the Lightweighting Advantage

With PET (polyethylene terephthalate) firmly ensconced as the material of choice for plastic container manufacturers, the focus has shifted to designing lighter-weight versions of current packaging to wring costs out of the equation and quench consumers' thirst for more sustainable products.

Although PET has been around for more than 40 years, advances in resin technology and conversion equipment have aided manufacturers' lightweighting efforts as they try to improve their environmental profile. Research conducted in 2010 for the International Bottled Water Association (IBWA) found that the average gram weight of a 16.9 oz. single-serve water bottle had shrunk by 32.5% over the prior eight years[1]. While the predominant current weight of 500ml PET water bottles in the United States is now as light as 8 grams (g), new launches are trying to squeeze that down even further.

Yet zeroing in on the optimal design that can offset lightweight material composition with a structure that still meets stringent performance requirements is no easy matter. In fact, it's a delicate balancing act that has sent brand owners, bottle manufacturers, resin and machine manufacturers scrambling to embrace innovative design processes that can help them achieve their goals.

At Plastic Technologies Inc. (PTI), a leader in plastic package design services, the go-to practice is simulation-led design that combines an in-house virtual-prototyping tool with finite element analysis from Dassault Systèmes' realistic simulation application SIMULIA, a key component of the Perfect Package Industry Solution Experience. Simulation enables the PTI design team to greatly reduce the amount of time and resources spent on building and testing physical prototypes.

PTI has a broad swath of clients ranging from consumer product companies to plastic processors and material suppliers. In a typical year, the firm performs as many as 500 unique design developments and an average of five iterations per design for clients, and it recently capped off its 10,000th bottle design since its inception in 1985. PTI employs state-of-the-art CAD tools, including Dassault Systèmes' CATIA application, in the development of innovative designs for its customers.

Abaqus is often employed in concert with PTI's proprietary virtual-prototyping software. This is used to simulate the reheating of preforms, replicate the blow molding of containers and predict the material thickness distribution of associated mechanical properties. The data is then used as input for FEA studies that explore the highly nonlinear deformation of different containers under various types of loading conditions.

Abaqus has become an essential part of PTI's development process, helping designers address mounting workload pressures by more quickly screening designs, identifying the best lightweighting opportunities, optimizing the production process and identifying root-cause failures.

"Our simulation results help in the development process in multiple ways," says Sumit Mukherjee, Director, CAE & Simulation at Plastic Technologies. "It helps screen the

"If new package designs can be simulated before any samples are made, bottle and preform design iterations happen more quickly and cheaply, speeding up the entire design chain and resulting in quicker time to market."

— Sumit Mukherjee, Director, CAE & Simulation, Plastic Technologies Inc.

1. An analysis performed by the Beverage Marketing Corp. for the International Bottled Water Association, www.foodbev.com/news/earth-day-finds-weight-of-plastic-bottles-reduced-by-32#.VC13nOvgWes

Source: SIMULIA Community News

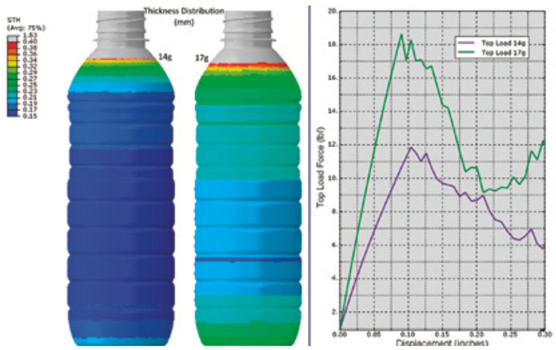


Figure 1. Top-load strength is predicted to drop nearly in half as container is light-weighted from 17 to 14 grams with thickness distribution comparison on left.

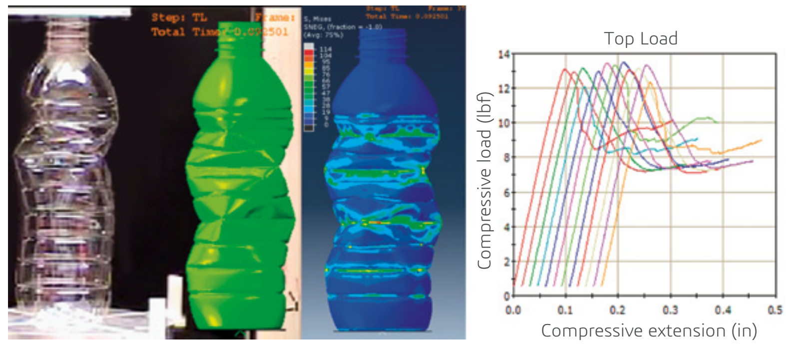


Figure 2. Comparison of actual and simulated Top-load performance of 14g container.

most promising candidates that are then refined further for optimum performance. It lets us provide critical feedback on what geometric features, material properties and thickness distribution will guarantee better performance and possible lightweighting for existing containers, and it encourages more innovative thinking to facilitate creative, viable solutions."

Adventures in container performance

PTI has two primary objectives when lightweighting container designs for its customers: to achieve materials savings without greatly affecting structural performance and to enhance both container structure and preform designs to improve the efficiency of material distribution so that each grain of material is maximized.

In one study that explored plastic water bottle performance during lightweighting, PTI used Abaqus in simulations of what happens to top-load strength and/or side-wall rigidity under varying pressures to ensure that a lighter plastic water bottle would not buckle under loading or stacking conditions. Surprisingly, it was revealed that the top-load strength of a plastic bottle drops nearly in half from 19 lbf (pound force) to 12 lbf as the container is light-weighted from 17g to 14g—a critical finding that allowed the company to redirect its design efforts quickly.

The simulated data was physically validated by molding samples at both 17g and 14g, and the predictions were within 90% of the actual observed values.

Abaqus was tapped to explore the orientation and wall thickness of the bottle sidewall to identify the optimal preform dimensions that would result in the desired top load. "Abaqus allows us to incorporate the right loads and boundary conditions along with the time scale of the particular applications," Mukherjee says. "Going forward, the potential for incorporating the structural dynamics with fluid contact interactions [as is typical of all containers encapsulating a fluid product] is perhaps the single most redeeming feature of Abaqus for us."

Design challenges come in all shapes and sizes

PTI also studied top-load and side-load performance of oval and other non-round containers to determine the different outcomes produced by different preform heating methods during the blow-molding process. In this case, PTI engineers learned that the "preferential heating" method is the preferred option for oval-shaped containers as it resulted in a more uniform weight distribution with better empty and filled top-load strength.

"This ability to analyze different container shapes and preform designs in a relatively short time meant a wider variety of design features could be rapidly evaluated while providing a good learning tool for future design recommendations," Mukherjee says. "This opens the door for evaluating more creative concepts that may fall outside of the scope of the previously prototyped concepts and allows for the development of more robust designs much more rapidly."

Going beyond lightweighting

Abaqus FEA is not only facilitating PTI's lightweighting efforts, it also plays a role in other areas of the design-and-build workflow, including optimizing a more complex blow-molding process and aiding in ongoing efforts to identify and fix product failures.

Consider the design and manufacture of wide-mouth PET containers, which are produced via a single-stage blow-molding process as opposed to the conventional two-stage process. The large neck diameter of this class of PET containers requires the single-stage process because the retained heat from injection molding can be harnessed for preform stretching and blow molding. Preform design is particularly critical because there is little room for redistribution of material with this approach. Historically, however, the complexity of the single-stage process has precluded PTI and others from accurately simulating preform design and the actual blow-molding process in a virtual world, continuing a reliance on costly physical prototypes.

Source: SIMULIA Community News

Now, building on its success modeling blow-molded wall-thickness distribution on round and oval containers, PTI was able to create its first-ever analytical model that addresses these specific challenges, simulating a pure single-stage process on a 116g 3L container that was blow molded without any additional reheat conditioning. By inputting the sidewall thickness and mechanical property outputs from virtual-prototyping software into Abaqus FEA, PTI wanted to predict container top-load resistance, the goal being to zero in on the optimal container size that could hold a kilogram of printer color toner.

PTI's simulations of this previously hard-to-replicate design and manufacturing process proved to be nearly identical to the results of physical testing. The failure mechanism and deflection at max load were also near mirror images between the simulation and the actual tested bottles. Abaqus' precise contact algorithms and its ability to efficiently map material properties to individual nodes and elements was instrumental in helping PTI pull off a simulation of this magnitude, Mukherjee says. "We had used other software in the past, but it didn't meet our needs for large deformation of thin-walled plastic articles with nonlinear material properties."

Mukherjee notes that having access to all the different solver modules, including structural dynamics and computational fluid dynamics (CFD) in Abaqus, and the option to scale to a higher number of CPUs based on complexity and need, is enabling the team to tackle a wider variety of challenging problems.

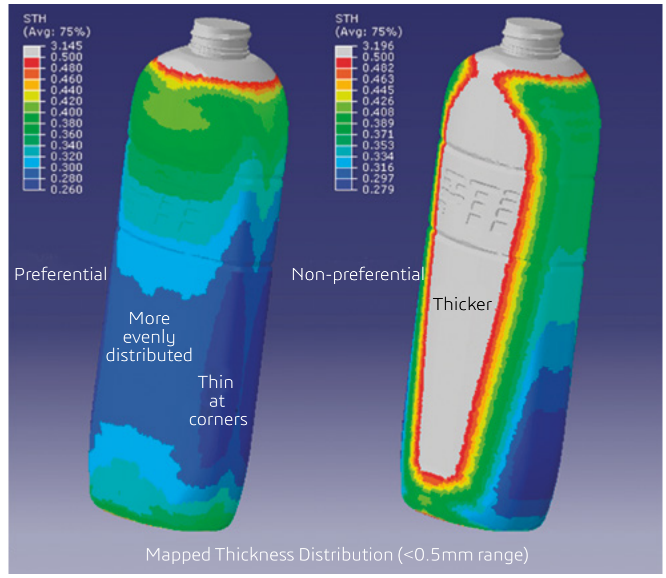


Figure 3. Abaqus FEA simulations revealed that the "preferential" heating method (left) is the better option for oval containers because it resulted in more uniform weight distribution and top-load strength.

Getting to the root of product failures

As packaging becomes an integral part of a company's brand appeal, new containers are testing current processes and domain expertise, introducing novel challenges in the way of package failures. Yet since quality standards vary from one producer to another, there is no absolute guidance on what constitutes failure.

PTI decided to further evolve its simulation efforts to tackle root-cause failure analysis and, ultimately, improve its quality efforts. Armed with its own virtual-prototyping software tools along with FEA software and M-Rule® models, PTI was able to zero in on reoccurring failures and resolve them in a fraction of the time and with far fewer resources than were previously required using standard prototype-and-test methods.

In one exercise, engineers tested their new failure-analysis process on a 64-ounce hot-fill juice container, which exhibited bulging in the area of the logo panel on sporadic numbers after being filled. Tracking the errors through the system, PTI determined that the failure sample was being generated during the filling process. Further analysis revealed that material distribution inconsistencies were not the cause of failure, prompting PTI to turn its attention to possible external influences. A thesis emerged that high product temperature coupled with filler pressure spikes was the impetus for the panel failure.

In order for simulation to serve as an effective replacement for the traditional root-cause failure inspection process, PTI had to conduct modeling efforts on a grand scale. The model's build began with the replication of the material distribution and mechanical properties, but also included reproducing the blow-molding process in a virtual world as well as the physical aspects of the environment, including conveyors and filling heads. Once the information input was complete, PTI conducted numerous simulations to realistically replicate the failure mechanism. With those validated, the team could then use the model as a baseline to compare design iterations that addressed the failure.

As a result of its efforts, PTI was able to rule out heavy-weighting the juice container design to a 75g version to address the deformation problem and instead concluded that a geometric modification to redesign the logo panel was the optimal resolution to the problem. This very process of continually modifying designs to eliminate failure is exactly where simulation can save time and money.

"If new package designs can be simulated before any samples are made, bottle and preform design iterations happen more quickly and cheaply, speeding up the entire design chain and resulting in quicker time to market," says Mukherjee. "A wide variety of design features can be rapidly evaluated, providing a good learning tool for future design recommendations. This opens the door for evaluating more creative concepts that may fall outside the scope of the previously prototyped concepts and allows the development of more robust designs much more rapidly."

Source: SIMULIA Community News

Keeping Carbonation Bottled Up with FEA

When Dom Pérignon—French Benedictine monk, winemaker, and namesake for fine champagne—was asked to look into why sparkling wine bottles were unexpectedly bursting in the cellars of his abbey in northern France three hundred years ago, he decided to investigate the bubbles. Fermentation, it turns out, continued after the beverage was bottled, producing additional carbonation and increasing pressure. By experimenting, so the story goes, Pérignon was able to control the refermentation process and reduce breakage and loss of the bottles' precious contents.

Today, research engineers working for Verallia at Saint-Gobain's Research Center, near Paris, take a different tack to ensure there is no breakage: They analyze the bottles, not the bubbly. Xavier Brajer, a mechanical engineer responsible for the 15-person Mechanics of Materials Group in the company's R&D department, leads these efforts. Central to the group's analyses are initiatives—from the government, wine and beverage industry, and Saint-Gobain itself—to reduce the quantity of raw materials used in the bottle-making process. "In order to reduce our impact on the environment, we want to minimize the materials and energy used," says Brajer, "and at the same time guarantee that the bottles have mechanical properties that will maximize their lifetime."

Glass bottles are made from four readily available sources: silica or sand, soda ash, limestone, and cullet (recycled glass). Coloring agents are also added, the specific color dependent on the beverage being bottled and the customer's wishes. An average empty 750 milliliter wine bottle weighs about 500 grams (some are as light as 300 grams), accounting for about 30 to 40 percent of the bottle's weight when full. A champagne bottle weighs about twice that amount. The sparkling beverage's heavier, thicker-walled container is required because of the pressures produced by its signature carbonation: reported to be as high as 90 pounds per square inch or approximately three times that of a typical car tire. While champagne produces the highest gas pressure of any beverage, every carbonated drink—including hard cider, soda, and other sparkling wines—creates internal stress on the glass that needs to be considered when designing lighter bottles.

Exploring bottle shape and strength with simulation and optimization

Despite the fact that beverage containers come in an almost unending variety of shapes, sizes, and colors, the profile of a champagne bottle is easily recognizable from across the room. Even the heft of the container is part of its perceived quality. Other bottle shapes are also closely associated with specific beverages or brands. So changing a bottle's shape to reduce weight and materials treads into sensitive territory. Given that, when it comes to making these changes, Brajer and his R&D team consider the subjective aesthetic factors. But they do so while relying on objective engineering tools.

"We start with a CAD model of the bottle shape that has been drawn by Verallia's design department, in agreement with the customer," says Brajer. "Then as we try and reduce the weight of the bottle, we use Abaqus finite element analysis (FEA) to simulate stresses and couple that with Isight software to optimize the geometry so that the container will withstand those stresses without breaking." Saint-Gobain has been using Abaqus for about 15 years, and started using Isight for automated and integrated simulation process flows about two years ago. "These two software packages link together easily and allow us to run a series of calculations that save time while leading us to the optimized bottle geometry," Brajer adds.

> **"In the past, it might have taken us a week to run the 100 simulations needed for this optimization. But now with an iterative looped process, it only takes about an hour."**
>
> — Xavier Brajer, Mechanical Engineer, Saint-Gobain Recherche

Source: SIMULIA Community News

In a recent optimization analysis, the Saint-Gobain research team tested a lightweight design for a hard-cider bottle. Like champagne, this carbonated alcoholic drink creates internal pressure loading that is most likely to rupture the bottle at its weakest point—the bottom. So while trying to reduce the overall amount of material, it is on this region that Brajer and his team focused their engineering analysis, looking to maintain its mechanical resistance and strength (see sidebar).

The team started the pressure analysis by first creating a model of a reference bottle in Abaqus: A 2D model utilizing glass' basic material characteristics was used to take advantage of the bottle's axisymmetric geometry and save computing time (see Figure 1). They then meshed the model and applied boundary conditions and loads. To optimize the geometric parameters (in this case nine, but sometimes more) that were used to describe the bottle's bottom—such as internal and external shape, curvature, and a number of different radii—Abaqus was coupled with Isight. This allowed the team to automate the simulation workflow and systematically make changes in the parameters, calculate stresses for each profile, and ultimately determine minimal stress and optimal bottle shape (see Figure 2). "In the case of the hard-cider bottle, we were able to reduce weight by 10 percent and stress on the critical bottom region by about 17 percent," says Brajer. "In the past, it might have taken us a week to run the 100 simulations needed for this optimization. But now with an iterative looped process, it only takes about an hour."

With the help of Verallia's technical teams, physical testing was also utilized to complement simulation. "How we use testing may change in the future," he adds, "because once we have calculations that validate the tests, design engineers will trust the virtual optimization process."

Simulation helps reduce bottle weight

Internal loading pressure is one of the most common causes of breakage for carbonated beverage containers. But it is far from the only one. As bottles move from the glass-making mold to the bottling assembly line and then finally to the store shelf—whatever the beverage or bottle—they are filled, capped, stacked, and transported. This subjects them to a variety of loading scenarios including thermal stress (from hot liquids), impact, squeezing, and compression. Basically, the life of a glass bottle can be a precarious one.

Brajer and his team are working to change that fact. So while the pressure analysis was the first optimization study that the engineering team conducted, they intend to use a similar process—and the same software tools—to investigate the other ways that bottles break. In future designs, using fewer raw materials will remain of primary importance to the team. That's one of the goals of Verallia R&D.

Internal Burst Pressure Simulation

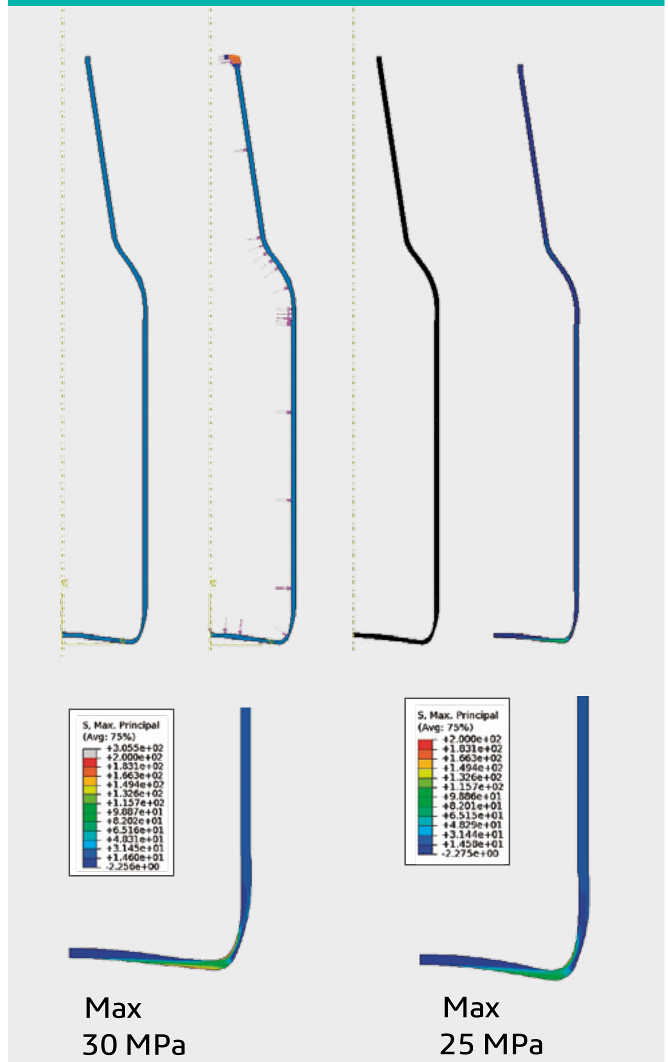


Figure 1. This simulation of internal burst pressure for a hard-cider bottle using Abaqus FEA shows (top, left to right for half-bottle models): geometry generation of the axisymmetric model; application of carbonation pressure loading and boundary conditions; meshing of the model; and analysis of stress results. In the detailed view of the bottle-bottom profile, internal pressure loading has been reduced from Max 30 MPa (bottom left detail) in the original bottle to Max 25 MPa in the modified/optimized version (bottom right detail).

This design strategy is critically important today given the need to reduce CO_2 emissions from manufacturing processes. "Our goal is to use less energy to produce each bottle," Brajer says. "If we reduce raw materials, we reduce the energy needed to process those materials and to melt and form the glass. The amount of CO_2 created in the process, in turn, is directly linked to the energy and raw materials usage."

Source: SIMULIA Community News

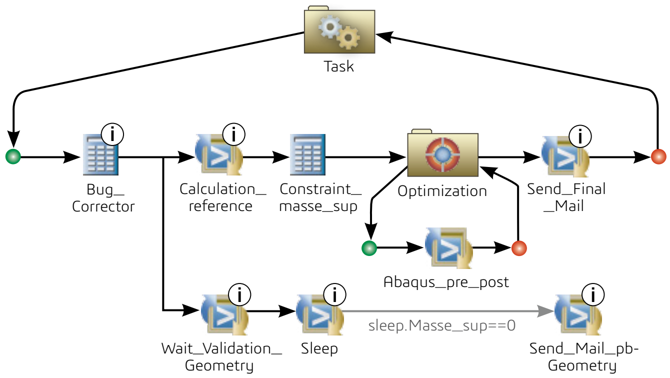


Figure 2. This Isight workflow, with an embedded Abaqus FEA loop, allowed the Verallia design team to systematically optimize bottle shape, making slight changes in the bottle's geometry parameters in each iteration. The automated process shortened analysis time from one week to one hour.

Given the quantities of bottled beverages and food consumed worldwide, the carbon footprint for bottle-making is worth addressing. Verallia, Saint-Gobain's Packaging Sector, is the second largest glass bottle and jar manufacturer in the world—with a yearly production of roughly 25 billion containers. Given that, it's easy to see how their design strategy to optimize weight could provide significant environmental benefits—plus champagne bottles that would have made Dom Pérignon proud. We can all toast to that.

Making and breaking glass bottles

The primary method for making narrow-necked bottles—like for champagne, hard cider, or wine—is a blow-and-blow process (as opposed to a press-and-blow method primarily used for wide-mouthed jars). Employing this technique, molten glass at 1500° C, straight from the furnace, is first cooled to 1100° C in a forming machine and then cut into "gobs" (small bottle-sized amounts). Compressed air is used to blow a cavity into the hot semi-liquid material creating an intermediate shape in the forming machine. A second jet of air gives its final shape to the bottle in the blow mold. An annealing process is utilized to give the glass additional strength.

Unfortunately, glass is impossible to manufacture without tiny defects, even though the glass-making process has had more than 5,000 years for technical advancement. These defects—such as small scratches or cracks in the surface—result from contact with objects and a variety of other factors and can cause a weakness in the material. "If you had a bottle without any defects," says Brajer, "glass bottles would be 100 times stronger than they are."

Since the behavior of defects can be predicted by probability, Brajer and his engineering team use Abaqus FEA and Isight to help calculate stresses against rates of failure, while also striving to minimize the amounts of raw materials used in the company's eco-designed line of containers. "Our goal is to find the lightest bottle that will withstand a statistically accepted maximum level of stress," says Brajer.

Source: SIMULIA Community News

Lighten up! Amcor Uses Realistic Simulation to Stay on Top in Plastic Container Market

Courtesy of Amcor

The dynamic, competitive landscape of the consumer packaged goods (CPG) industry demands nimble adaptative strategies. PET (polyethylene terephthalate) plastic container manufacturers are juggling business consolidation, increasing government regulation, and the need to demonstrate corporate and social responsibility. At the same time, ever-changing consumer preferences as well as energy and raw material costs are driving an exponential expansion of product portfolios. The PET customer is demanding that manufacturers develop a wider variety of top-quality, innovative containers in ever-shorter time periods and at lower unit prices.

To meet these challenges, the world's largest supplier of PET containers, Amcor's Rigid Plastics Division (renamed from Amcor PET after its parent bought Alcan in late 2009), has found a way to significantly reduce costs—from product design to materials parameters to methods of production—while adhering to strict industry performance standards. They use Product Lifecycle Management (PLM) solutions from Dassault Systèmes to integrate 3D virtual design, finite element analysis (FEA), and collaborative product development software into their product design and development process.

The results: a 50 percent drop in design cycle times, enhanced communication between designers and engineers, less physical prototyping, and faster time-to-market. Plus quicker, more creative response to customer requests for new ideas—and lighter-weight, high-performance product solutions that lower everyone's costs all along the supply chain from raw materials to transportation.

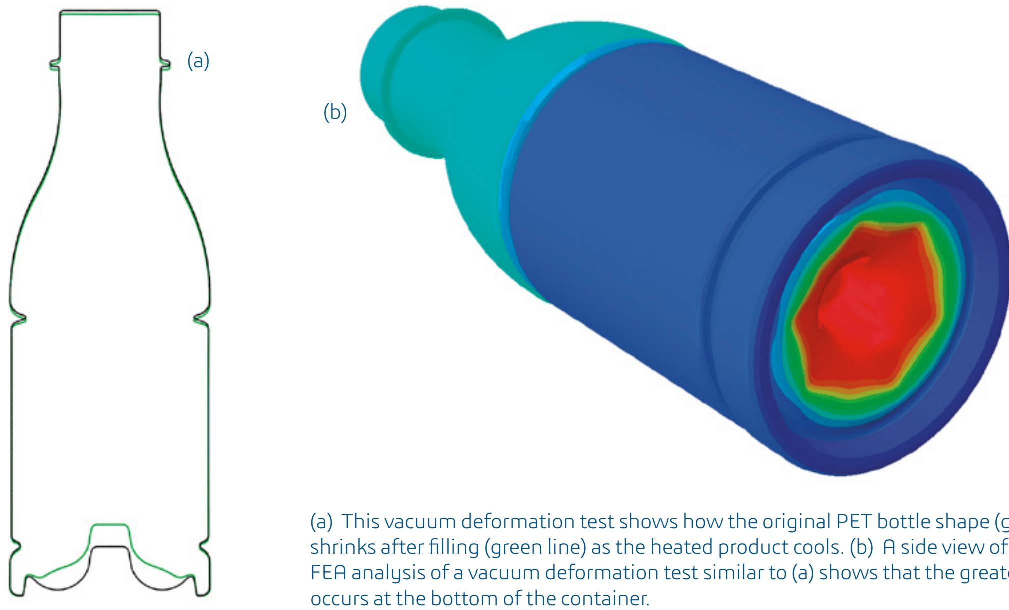
A few grams shaved means millions saved

Amcor's Rigid Plastics Division has 63 facilities in 12 countries that provide packaging for many of the world's leading brands of carbonated soft drinks, juices, teas, water, condiments, salad dressings, sports drinks, soaps, shampoos, pharmaceutical and health care products. The Michigan-based Division produces about 25 billion units of bottles, jars, cans and other product configurations per year. Multiply that number by even a few grams saved per unit and the sustainability impact is staggering. "A container made with too much, or too little, material can be very expensive," says Amcor's Advanced Engineering Services group manager Suresh Krishnan. "Too little material can lead to containers failing, and too much can cost us a fortune. 'Lightweighting' our products is one of the key things that has sustained Amcor against our competition during these tough times, and computer-aided engineering (CAE), within a PLM environment, has been critical to achieving that."

The goal of 'lightweighting' resonates with engineers in every industry, from aerospace to cell phones. But the weight savings of plastic over glass have dramatically transformed the liquid container business in recent decades. While glass has been used for centuries, and its physical properties are well known, the move to PET in the 1970s required a step-up in sophistication on the part of manufacturers.

"Origami" concept vacuum panels are included in a PET container for designed collapse that compensates for shrinkage during cooling to maintain structural strength and integrity. Original shape is clear, final shape is green.

Source: SIMULIA Community News



(a) This vacuum deformation test shows how the original PET bottle shape (gray line) shrinks after filling (green line) as the heated product cools. (b) A side view of an Abaqus FEA analysis of a vacuum deformation test similar to (a) shows that the greatest load (red) occurs at the bottom of the container.

Simple product, complicated design challenge

"A PET container is a simple product, but it's a complex design problem to make it right," says Krishnan. For example, the popular two-liter carbonated soft-drink bottle, seen on supermarket shelves everywhere, has to be custom-designed to individual brand specifications and must retain its blow-molded shape during cold-filling, carbonation, sealing, labeling, packing and shipping (hot-filled containers need to withstand additional temperature, vacuum and pressure fluctuations). No container should fail if accidentally dropped, nor excessively dent or lean when stacked.

To cost-effectively produce such a high-performance product, Amcor's Advanced Engineering Services group uses computer modeling to simulate, or virtually test, the behavior of a bottle under these diverse loads and stresses while it's still in the design stage. At the core of their regimen is Abaqus Unified Finite Element Analysis (FEA) software from SIMULIA, the Dassault Systèmes brand for realistic simulation. Amcor employs Abaqus to generate simulation data that can guide design modifications, material thickness parameters, even manufacturing processes, in order to reach the lightest possible result that satisfies both customer and regulatory requirements.

Visualizing the challenges

Based on an initial concept that the industrial design department has worked out with the customer, the design engineers start by building a 3D virtual model in CATIA. They then use customized scripts and knowledge templates within CATIA to accurately determine the critically important surface area, volume and weight for the bottle's final design. "CATIA's capabilities save us a lot of time," says Krishnan. "Whenever the analysis shows that we need to make a design change, we can do so and the model automatically adjusts to reflect that. And instead of starting a new design from scratch, we can begin with an existing design and quickly modify it."

Next, the engineers mesh the geometry of the virtual bottle with either Hypermesh or Abaqus/CAE ("our designers are increasingly using Abaqus/CAE because it has a CATIA-like look so it's easier for them to work with," says Krishnan), then bring it into Abaqus Unified FEA for physics-based performance simulation. A typical Abaqus model for a top load analysis (such as bottle capping, or container stacking) has about 150,000 shell elements and about 350,000 degrees of freedom. A more complex, Coupled Eulerian-Langrangian drop analysis (which simultaneously shows the fluid-structure interactions between a container, its contents, and the floor) can have up to 800,000 d.o.f. The group runs their analyses on a Microsoft Windows HPC Server.

Amcor tried a different FEA software in the past, but realized they were not getting satisfactory results and switched to Abaqus, a change that empowered the group to begin exploring the full scope of their design challenges. "Abaqus was the better choice for us because it offered a breadth of simulation disciplines that cover more significant performance requirements for PET containers," says Krishnan.

Kicking the container around with simulation

And it's quite a range of disciplines. The group began with top loading and vacuum pressure simulations. They moved on to drop-testing, blow molding, conveyance, denting, and

Source: SIMULIA Community News

leaning. They are currently working on pasteurization and retort (heating during sterilization) simulations. And they're even starting in on ergonomics, to simulate the effects of a human hand putting pressure on a container. "Being able to simulate multiple load conditions at the same time is very important to us," says Krishnan. "You have to take into account a number of parameters simultaneously, such as fluid-structure interaction, temperature, pressure, and material strain rate."

With their FEA results in hand, the Advanced Engineering Services group has a clear vocabulary for discussing the viability of a design with the industrial designers. Using multiple iterations between CATIA and Abaqus, the parties can collaborate to arrive at the best solution that validates the appearance, performance and functionality of a particular container. Such improved communication pays off: "One of our performance metric targets was to reduce the number of design revisions we made by 20 percent in a year," says Krishnan. "Right now we are well ahead of that goal."

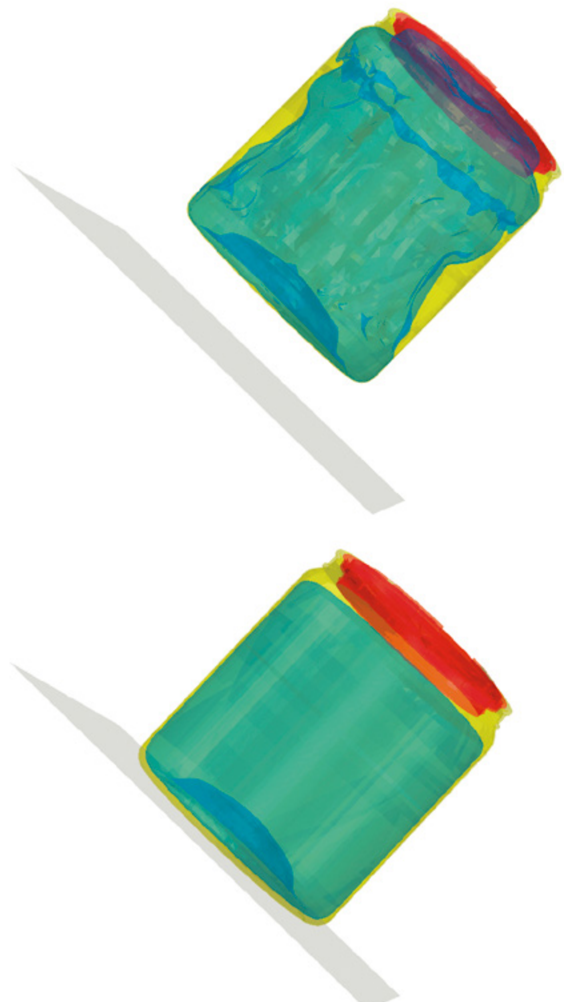
"The benefits from virtual testing can extend beyond the testing laboratory all the way to manufacturing," Krishnan says. "When we achieve an optimum top load value via simulation, we can use that data to provide actual section weights to the process engineers in the plant, so they can more easily produce the container that gives the desired performance."

PET plastic behavior is complex

The PET material itself brings unique challenges to this whole process. PET is highly nonlinear, with biaxial properties that vary with the amount of stretching it undergoes. A semi-crystalline thermoplastic, PET softens at a "glass transition temperature" of approximately 76 degrees C. Above that, it becomes elastic and can be formed, a property effectively utilized in the stretch blow molding process.

But when PET containers are filled with a hot liquid, they are susceptible to shrinkage back towards their "remembered" previous shape (the preform), a characteristic that has to be taken into account when designing the initial container configuration. The bottles also collapse slightly due to vacuum pressure resulting from cool-down after hot-filling. So the design for a hot-fill PET bottle includes 'vacuum' panels for designed collapse. "We can now easily model these kinds of physics-based characteristics with Abaqus FEA, using a customized script for hydrostatic fluid elements that enables us to accurately simulate the behavior," says Krishnan.

The contents of every type of PET container must also be taken into account in Amcor's simulations, from adjustments in the density and viscosity values of liquids (from pure water to sticky paint) to the internal pressure fluctuations inherent to carbonated soft drinks.



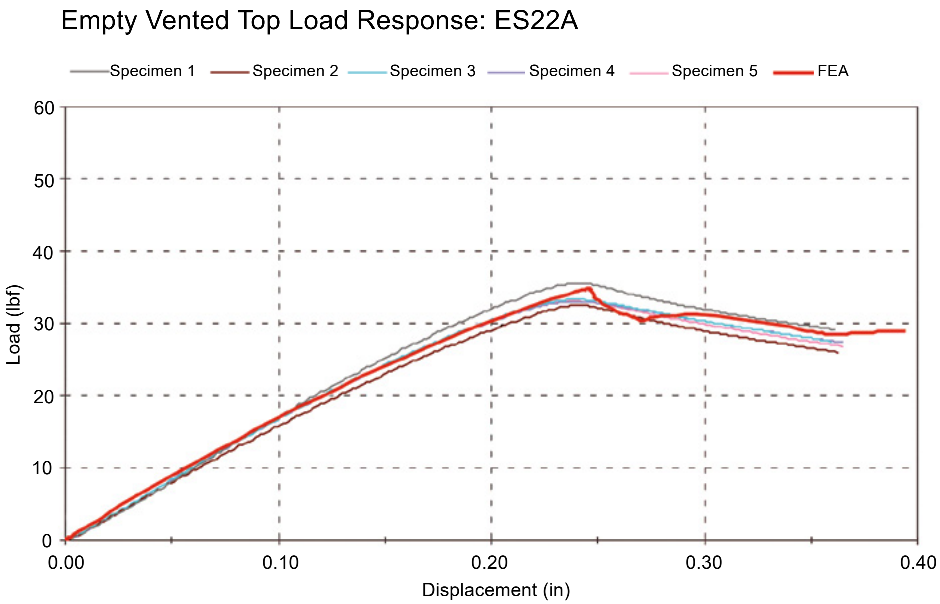
Abaqus FEA container drop test uses a coupled Eulerian-Lagrangian analysis to show the interaction between the container, the fluid it holds, and the surface it impacts. The top must stay on even when the container is dropped 3 ½ feet to a hard floor.

Amcor continues working on advanced material properties for their models. While PET is 100 percent recyclable, containers made from recycled PET (RPET) may have slightly different material properties than the originals. Initiatives also are underway in the industry to develop biodegradable PET using ethanol. "Although we are not simulating either of these materials at the time, this is certainly a consideration for the future," says Krishnan.

Managing all that data

It all adds up to a vast amount of simulation data. Amcor keeps track of everything the Advanced Engineering Services group generates by using ENOVIA from Dassault Systèmes

Source: SIMULIA Community News



Graph of empty vented top load response test results shows how accurately Abaqus FEA (red line) predicted the behavior of the container.

for collaborative product development, which facilitates the organization and easy retrieval of all CATIA and Abaqus data for each container design while managing all processes to keep them in synch.

"Whoever in our organization—from the Advanced Engineering Services group of 14 engineers all the way to our manufacturing plants—needs information about a specific project, they can pull up the report in ENOVIA and find the latest version, completely standardized, which is very helpful," says Krishnan. "ENOVIA automatically saves the history of every previous iteration as well, allowing for easy reference, tracking and communication among our project teams."

Results rise to the top with simulation-driven lightweighting

The growth of Amcor's physics-based simulation capabilities has been the driving force behind the company's lightweighting initiative. Krishnan cites one example where a 63-gram container design was reduced to 43. "We used realistic simulation to validate performance while trying out various Amcor-developed technologies and eventually met all performance requirements with the lighter design," he said. "Simulation helped us try many more options than we normally would and compare multiple designs with one another."

Although Amcor still validates their virtual tests with physical testing, the ever-increasing accuracy and refinement of their computer predictions has allowed them to decrease physical prototyping dramatically. "We see a close match between the curves that Abaqus provides and the test results so we've got a lot of confidence in simulation now," says Krishnan. "We've cut our design cycle down to nine months from 12 to18, which has significantly reduced our product development costs. And we've gained a lot of management buy-in to our methodology."

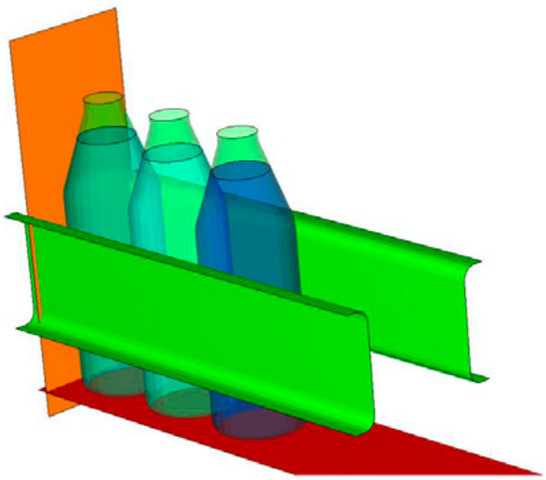
CAE promotes creativity

Another area in which the use of CAE has proved of value for Amcor is when proposing new ideas to clients, Krishnan says. "We include animations of our Abaqus simulations in all our presentations. We can demonstrate how we create a design, perform FEA on it, and try out as many options as we want." Any industrial design proposal can be quickly simulated; if a customer puts in a request in the morning, animations can ready by that evening. "It really frees the designers to explore whatever ideas they have," says Krishnan.

"It's a fast-changing business and the next new design is just around the corner," he adds. "Somebody else is always looking to capture that design so we have to be really fast—and with CAE in our arsenal, we are."

Source: SIMULIA Community News

Bottle Conveying System Analysis



Summary

A key factor in the design of bottles and packaging containers is performance during conveying. The ability of a bottle to remain standing while traveling through a conveying plant for production, cleaning, filling, packaging, etc. allows that plant to be automated. If bottles fall or jam during conveying then human intervention is required to correct the situation. Finite element analysis can be used to verify new bottle designs and ensure that changes to current designs will not cause a reduction in conveying performance.

Background

Physical testing to evaluate the performance of bottle designs on conveying systems is expensive and time consuming. Any problems or failures found late in the design cycle can cause large delays in a product release schedule, particularly if the changes needed to remedy the issue are sufficiently large as to require consumer testing of the new design. Simulating the conveying process with the finite element method can allow designers to more quickly make decisions about changes to existing bottle designs, to validate new designs, or to compare performance between designs.

This technology brief describes an example of the analysis of a conveying system for fluid filled bottles. The purpose of the analysis is to determine whether the bottles will remain standing during a surge test. This is a two stage test: first, the bottles impact a closed gate while the conveyer belt is moving, then the gate is opened and the bottles accelerate back up to the speed of the belt.

Finite Element Analysis Approach

The various parts in this model are meshed as separate bodies, with contact definitions defined at the interfacing surfaces. Abaqus/Explicit contains a general contact algorithm, which allows for very simple definitions of the complex contact interactions between many bodies.

Abaqus/CAE is built on the concept of parts, instances and assemblies. With this methodology it is straight forward to create a mesh for one bottle, and then generate an assembly that contains multiple instances of that bottle. Each instance will automatically have the material and section assignments, and the surfaces and sets, which were defined for the original part. Options and tools exist for positioning the instances relative to each other in the assembly, such that the correct initial model configuration can be defined.

This approach also makes it very straight forward to remove the fluid and perform the simulation on empty bottles. A variety of tests can therefore be performed by making simple, minor changes to the model.

The model used in this technology brief contains one bottle definition and one fluid definition. These parts are then instanced three times each, and each instance is initially translated along the conveyor belt to give the correct starting position. If more bottles were to be added, then additional instances could be simply defined. With this methodology there is no need to have a complete, separate definition for each body in the model.

Shell elements are used for the bottle and the mesh can be seen in Figure 1. The high-density polyethylene (HDPE) of the bottle is represented with an elastic-plastic material model.

Solid hexahedral elements are used for the fluid and the mesh can be seen in Figure 2. Adaptive Lagragian-Eulerian (ALE) meshing is used for the fluid to maintain good element shapes during the large deformations that the fluid experiences. The ALE method can also smooth and improve the initial mesh.

Key Features and Benefits

- Explicit dynamic solution method for efficient analysis of transient, highly nonlinear problems
- Equation of state models for fluid constitutive behavior
- Automatic adaptive meshing to maintain fluid mesh quality
- Robust contact algorithm
- Part, instance, assembly methodology for simple model set up and expansion

Source: Abaqus Technology Brief

The fluid is represented with an equation of state material model, which can be used to characterize incompressible and inviscid fluid response. The equation of state determines the volumetric strength of a hydrodynamic material and specifies the pressure in the material as a function of density and internal energy. The deviatoric strength of the material is considered separately and can be included if viscous behavior is needed.

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Abaqus/Explicit offers alternative kinematic formulations for solid hexahedral elements, and when appropriate for the analysis, choosing a non-default formulation can significantly reduce computational expense. For the elements representing the fluid in the present simulation, an orthogonal formulation is chosen. This formulation provides a good balance between computational speed and accuracy.

If the objective of the analysis was to determine the shape of the fluid free surface with the highest possible accuracy, the default kinematic formulation would be appropriate. However, because the inertial coupling of the fluid and structure is of primary importance, a less computationally expensive formulation can be used.

The conveyor belt, guide rails and gate are considered as rigid for the purpose of this analysis, and are meshed using rigid elements. The undeformed configuration of the full system can be seen in Figure 3.

Contact is defined between the inner surface of each bottle and the outer surface of the corresponding fluid mesh, between each pair of neighboring bottles, between the first bottle and the gate, and between all bottles and the guides and conveyor belt.

This example considers bottles that have been filled, but are not yet sealed. So, no gas pressure or seal are included in the model.

Gravity loads are applied to both the fluid and the container. The conveyor belt is given a constant velocity throughout the analysis. The gate is initially closed, and then it opens once all the bottles have impacted against it, and settled.

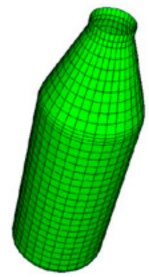

Figure 1: Bottle mesh

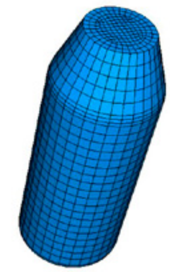

Figure 2: Fluid mesh

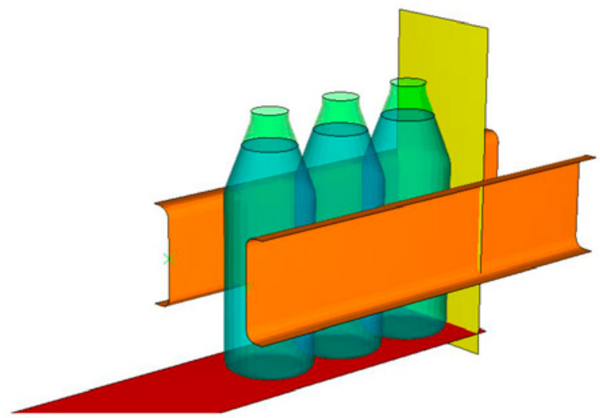

Figure 3: Initial model configuration

Analysis Results and Discussion

Some representative results from the analysis are presented below.

The sequential plots in Figure 4 (next page) show the fluid sloshing in the bottles during impact (left column) and acceleration (right column).

The main purpose of this analysis is to determine whether the bottles remain upright during the deceleration and acceleration caused by the impact with the gate. The deformed shape plots show that this design of bottle would pass this test.

Conclusions

As demonstrated in the above analysis, Abaqus/Explicit can be used to incorporate the effects of sloshing-type fluid-structure interaction into dynamic analyses. While it is generally not possible in Abaqus/Explicit to model complex fluid flow behaviors or phenomena such as free-surface interactions and splashing, inclusion of the inertial loading caused by the fluid deformation allows for a more complete simulation capability.

Source: Abaqus Technology Brief

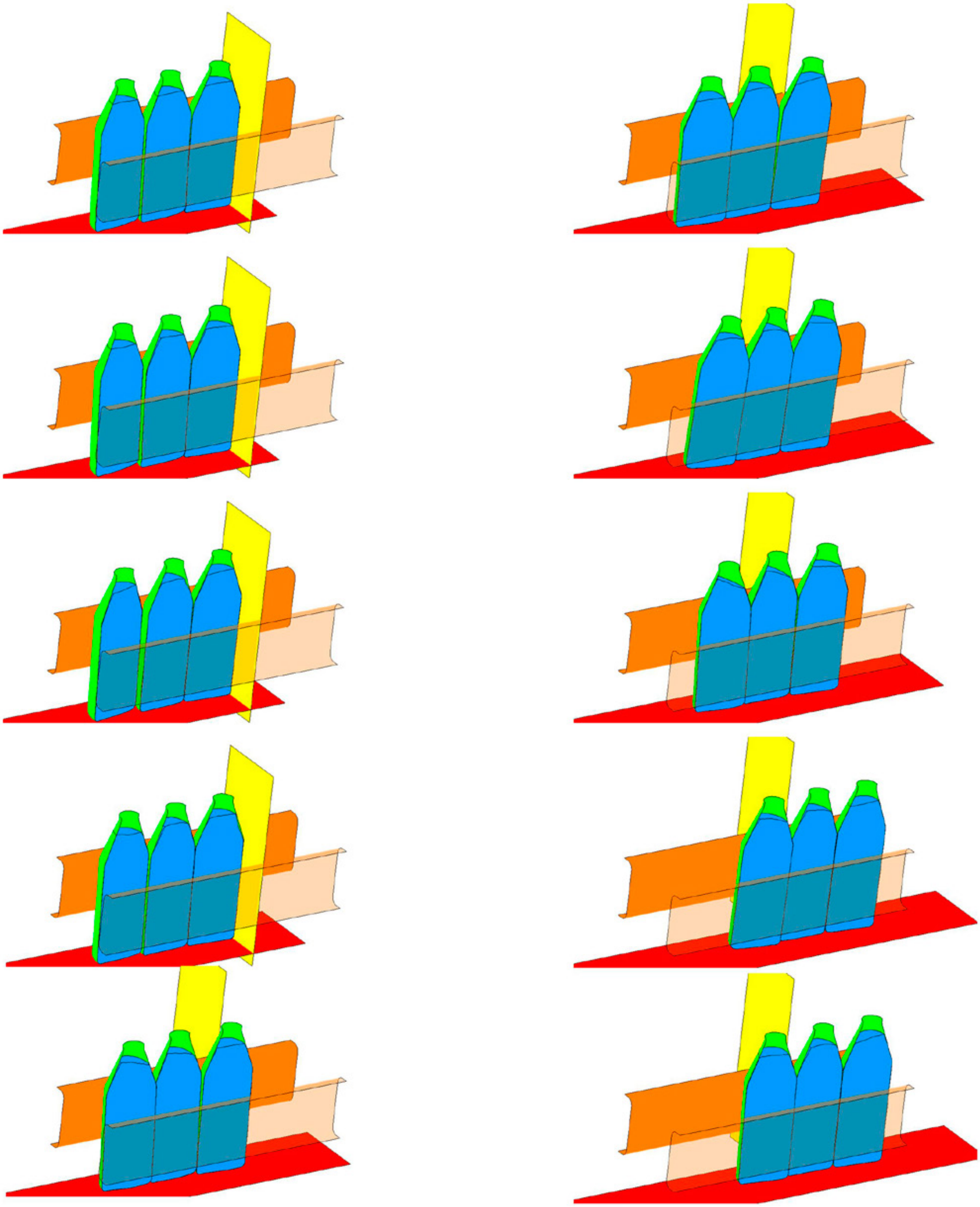

Figure 4: Sequence showing fluid sloshing in bottles during impact (left) and acceleration (right).

Source: Abaqus Technology Brief

References

1. Consumer Products Simulation with Abaqus webinar, presented jointly between Abaqus and The Procter & Gamble Company. http://www.simulia.com
2. Bottle Conveying Simulation – Henning, D., The Procter & Gamble Company, Stevens, J., Stress Engineering Service, Inc., and Kumar, S., Abaqus Central, Inc. Abaqus Users' Conference 2004.
3. Abaqus for Package Development at Procter & Gamble – Henning, D. B., and Loudin, B. K., The Procter & Gamble Company. Abaqus Users' Conference 2002.
4. Abaqus Technology Briefs: Fluid-Structure Interaction Simulations. http://www.simulia.com/

Abaqus References

For additional information on the Abaqus capabilities referred to in this brief please see the following Abaqus 6.13 documentation references:

- Analysis User's Guide

  "Explicit dynamic analysis," Section 6.3.3

  "ALE Adaptive meshing," Section 12. 2

  "Equation of state," Section 25.2.1

- Example Problems Guide

  "Cask drop with foam impact limiter," Section 2.1.12

  "Water sloshing in a baffled tank," Section 2.1.14

- Benchmarks Guide

  "Water sloshing in a pitching tank," Section 1.12.7

Source: Abaqus Technology Brief

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